Increase in Airway Obstruction between 1993 and 2012 in Switzerland. An Observational Study

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Abstract: Rationale: Most studies determining the prevalence of airway obstruction are limited to short time periods.Objectives: Because temporal trends of obstruction in populations are largely unknown, we determined the prevalence of airway obstruction over 20 years in yearly general population samples in Switzerland between 1993 and 2012.Methods: We analyzed data of 85,789 participants aged 35 years and older who provided spirometric measurements as part of the LuftiBus lung function campaign. We linked data from the 2003-2012 period to the Swiss National Cohort to adjust for annual population differences. Spirometry was performed without bronchodilation, according to American Thoracic Society guidelines. We used Global Lung Initiative (GLI) and Hankinson reference equations to identify obstruction.Results: Obstruction prevalence increased between 1993 and 2012 from 6.1% (95% confidence interval [CI], 5.5 to 6.7) to 15.6% (95% CI, 13.8 to 17.3) based on GLI estimates and from 5.3% (95% CI, 4.7 to 5.9) to 15.4% (95% CI, 13.6 to 17.1) based on Hankinson estimates. When adjusted for participant demographics, air pollutant and occupational exposures, altitude, and season, the prevalence ratios of obstruction were 1.54 (95% CI, 1.22 to 1.93) and 1.65 (95% CI, 1.33 to 2.04) for GLI- and Hankinson-defined airway obstruction, respectively, for 2012 compared with 2003.Conclusions: Though prebronchodilator measurements likely overestimate the prevalence of airway obstruction in absolute terms compared with post-bronchodilator measurements, we found an increase in airway obstruction prevalence. Even with adjustment for several well-known risk factors for obstruction to make the populations across the years more comparable, we still saw a statistically significant increase in prevalence over this time period.

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An Observational Study

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Abstract

Rationale: Most studies determining the prevalence of airway obstruction are limited to short time periods.

Objectives: Because temporal trends of obstruction in populations are largely unknown, we determined the prevalence of airway obstruction over 20 years in yearly general population samples in Switzerland between 1993 and 2012.

Methods: We analyzed data of 85,789 participants aged 35 years and older who provided spirometric measurements as part of the LuftiBus lung function campaign. We linked data from the 2003–2012 period to the Swiss National Cohort to adjust for annual population differences. Spirometry was performed without bronchodilation, according to American Thoracic Society guidelines. We used Global Lung Initiative (GLI) and Hankinson reference equations to identify obstruction.

Results: Obstruction prevalence increased between 1993 and 2012 from 6.1% (95% confidence interval [CI], 5.5 to 6.7) to 15.6% (95% CI, 13.8 to 17.3) based on GLI estimates and from 5.3% (95% CI, 4.7 to 5.9) to 15.4% (95% CI, 13.6 to 17.1) based on Hankinson estimates. When adjusted for participant demographics, air pollutant and occupational exposures, altitude, and season, the prevalence ratios of obstruction were 1.54 (95% CI, 1.22 to 1.93) and 1.65 (95% CI, 1.33 to 2.04) for GLI- and Hankinson-defined airway obstruction, respectively, for 2012 compared with 2003.

Conclusions: Though prebronchodilator measurements likely overestimate the prevalence of airway obstruction in absolute terms compared with post-bronchodilator measurements, we found an increase in airway obstruction prevalence. Even with adjustment for several well-known risk factors for obstruction to make the populations across the years more comparable, we still saw a statistically significant increase in prevalence over this time period.

Keywords: obstructive lung diseases; prevalence; epidemiology; environmental pollutants; occupational exposure

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Author Contributions: E.A.W., A.S., C.W., and M.A.P. contributed to the conception and design of the study. A.T. provided the LuftiBus dataset and M.B. the anonymized data from the Swiss National Cohort (SNC). E.A.W. and A.S. cleaned and prepared the LuftiBus-SNC dataset. K.d.H. and M.R. provided the outdoor air pollution data. A.S. and H.D. assigned the exposures to the occupations. E.A.W. and C.W. conducted the statistical analyses. E.A.W., A.S., C.W., A.S.B., and M.A.P. contributed to the interpretation of data and drafted the manuscript. All authors commented on the manuscript.

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Chronic lung diseases characterized by airway obstruction (AO), such as asthma or chronic obstructive pulmonary disease (COPD), contribute substantially to morbidity and mortality worldwide. Although asthma is the most prevalent obstructive lung disease, COPD is the third leading cause of death (1). COPD and AO are insidious in that the latency period for the development of clinically significant disease takes several decades, and there are many known and potentially unavoidable risk factors, such as outdoor air pollution, smoking, and occupational exposures. Authors of a recent systematic review (2) found large global variation in COPD prevalence, ranging from 9.7% in Southeast Asia to 13.7% in Europe and 15.2% in the North and South American regions in 2010. Such prevalence estimates of AO or COPD are based primarily on cross-sectional studies with one reference date.

Repeated cross-sectional and longitudinal prevalence study designs exist. However, these designs are rare, hindered by time-consuming data collection and large–sample size demands. Nevertheless, studies with repeated measurements provide rich information because they can be used to reveal patterns of change in temporal trends. These studies show a wide range of prevalence trends across countries (3–13). Some of the differences in prevalence trends may be due to methodological variation, study populations, and lung function equipment or performance, making a comparison of prevalence data difficult. The few temporal trend studies on AO carry limitations: They are often restricted to two reference dates, are based on physician-diagnosed COPD instead of spirometric measures, or use the fixed-ratio criteria (3, 5, 6, 8–11). Although some temporal trend studies analyzed factors affecting prevalence, such as occupational exposures or outdoor air pollution, they similarly included either just two reference dates or a subset of these exposures (3, 4). Given these considerations, there is a lack of temporal trend studies on AO that include multiple reference dates and adjust for risk factors that confound temporal trend estimates.

Our aim was to assess the temporal trend of AO prevalence from 1993 to 2012 in Switzerland, a country that offers great diversity in terms of its population, geography, and exposures associated with AO. We performed a series of sensitivity analyses to test the robustness of the trend estimates and included important confounders in our analyses.

Methods

Study Design and Population

The full description of our methodology can be found in the online supplement. We used a cohort of 85,789 adults in a series of 18 prevalence studies from 1993 to 2012 for the primary analysis (Figure 1), comprising data from the LuftiBus project of the Zurich Lung Association, a not-for-profit health organization (www.lunge-zuerich.ch/de/projekte/luftibus), and the Swiss National Cohort (SNC) (www.swissnationalcohort.ch). The LuftiBus drove around Switzerland between 1993 and 2012, offering spirometry and other tests (e.g., exercise capacity tests) as well as preventative/therapeutic services for lung diseases to the general population. The SNC is a nationwide, census-based cohort combining individual data from the federal population censuses taken in 2000 and 2012, covering all residents of Switzerland.

For the secondary analysis, we linked the 2003–2012 LuftiBus data with the SNC to incorporate important risk factors for AO and demographics for participants. The years before 2003 could not be linked to the SNC, owing to a lack of person-identifying data for the linkage. We were left with a cohort of 29,189 subjects for this analysis (Figure 1). We conducted sensitivity analyses by looking at the subgroup of 1,175 participants who self-reported having asthma as well as 18,597 participants who reside in the Canton of Zurich. The Ethics Committee of the Canton of Zurich approved this study (BASEC-Nr. 2017-01804).

Because no date of birth in the LuftiBus data was available for 1993–2002, these years could not be linked with the SNC. Hence, we conduct two separate analyses: *1*) The primary analysis provides yearly, adjusted prevalence data of AO from 1993 to 2012; and *2*) the secondary analysis provides predicted marginal probabilities of AO based on the 2003–2012 data with adjustments for additional important confounders (Figure 1).

Spirometry

Spirometry was performed during the LuftiBus assessment using a computerized pneumotachograph (SensorMedics Vmax Legacy 20c spirometer with Vision 7-2b software; Viasys). In 2005, the device was replaced with the SensorMedics Vmax Encore 20c, and in 2011, it was replaced with the CareFusion MasterScreen Pneumo (Vyaire Medical). We defined AO diagnosis as a forced expiratory volume in 1 second over forced vital capacity (FEV_1/FVC) ratio below the lower limit of normal using the equation derived from the Global Lung Initiative's (GLI's) reference values for spirometry (14), by the Hankinson reference equations (15), and the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria of FEV_1/FVC less than 0.7 (16). We defined AO as meeting these criteria for COPD diagnosis; however, because only prebronchodilator data were used, we refrain from calling the outcome "COPD."

Statistical Analysis

All analyses were conducted using R version 3.6 software (17). The primary analysis was a generalized linear model with GLI, Hankinson, and GOLD AO as the outcome using Poisson error distribution and robust standard errors. We used these models to plot the predicted marginal probabilities annually, stratified by sex and smoking status. To include more confounders in the 1993–2012 dataset, we linked postal codes from the 2003 to 2012 dataset. Because of an inability to link postal codes to the year 2002, that year was not included in the plots. To guide visualization of the prevalence trends, we applied locally weighted regression (locally estimated scatterplot smoothing [loess]) for nonparametric smoothing (18).

To make the demographics across the years more comparable, the regression models were adjusted for age, sex, body mass index, smoking status, residential distance to major roads, urbanization, residential altitude, and season of LuftiBus measurement. Age, sex, body mass index, and smoking status were included in the analysis as important demographic confounders for AO. We used residential distance to major roads (>5,000 average daily traffic) and urbanization as composite markers for outdoor air pollution because evidence suggests these are associated with COPD (19–21). Residential altitude and season were included to adjust for differences in location and time of year.

For the secondary analysis, we calculated the predicted marginal probabilities of GLI-, Hankinson-, and

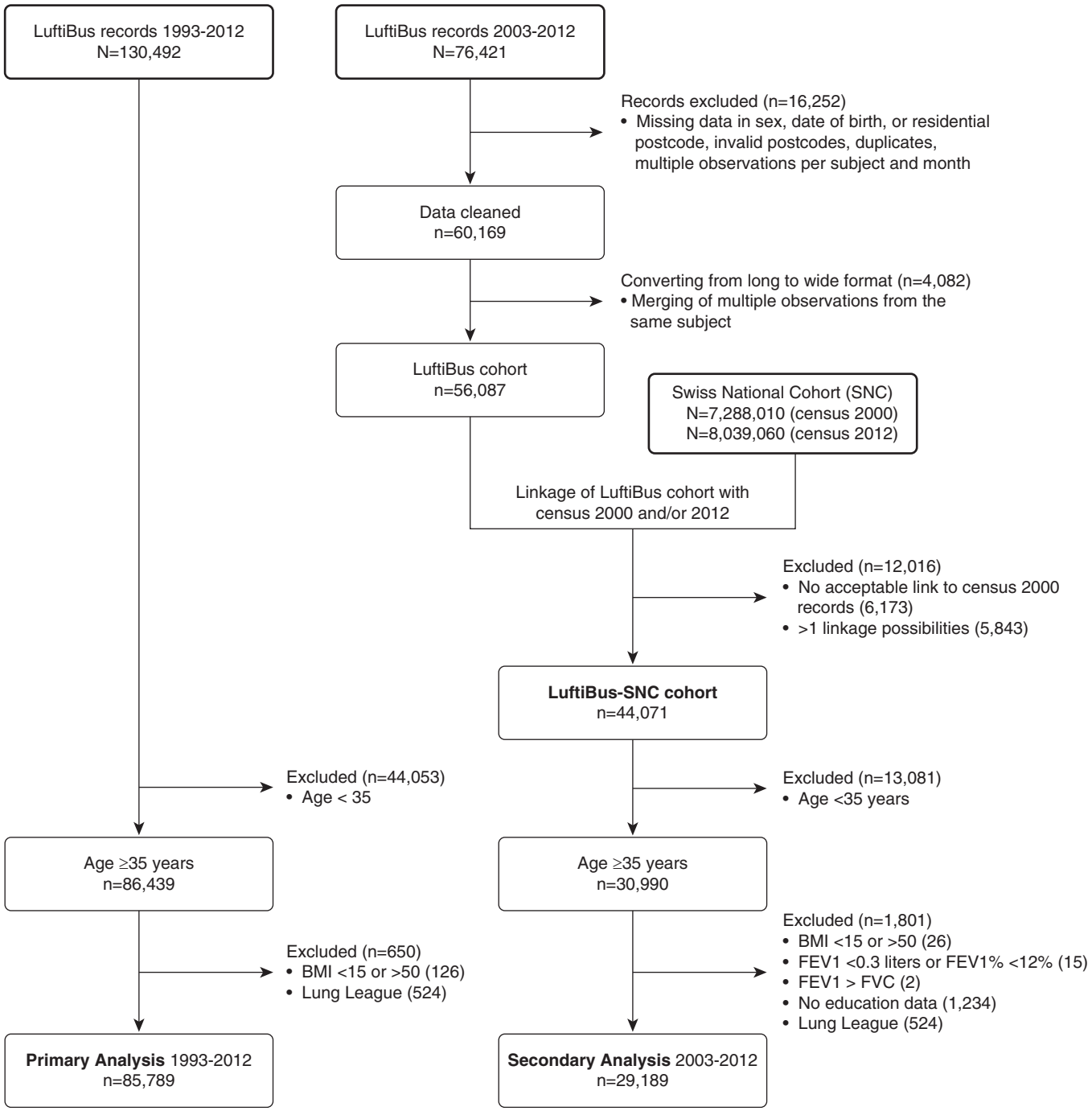

Figure 1. Study flowchart. BMI = body mass index; FEV_1 = forced expiratory volume in 1 second; FVC = forced vital capacity; SNC = Swiss National Cohort.

GOLD-defined AO annually using Poisson regression, with the year 2003 as a reference using the 2003–2012 LuftiBus-SNC dataset. These models were adjusted for the same risk factors as above, with the inclusion of education level; occupational exposure to vapors, gases, dusts, or fumes (VGDF); and participation in COPD Roadshow. Both education level and VGDF are shown to be correlated with AO (22–25). The COPD Roadshow was included because participants were more likely to have higher rates of lung disease than the general population.

We performed additional analyses to check the robustness of the observed temporal trend. We repeated the adjusted analysis, isolating the Canton of Zurich. This canton includes one-sixth of the Swiss population and is the most represented throughout 2003–2012, and the demographic is representative of the overall demographic of Switzerland (26, 27). We also annually calculated the proportion of

Table 1. Demographics, by year

	1993	1994	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
n	5,875	5,215	5,529	4,830	5,560	3,277	5,291	4,512	4,498	2,844	2,052	4,033	3,536	2,795	2,959	2,541	3,405	3,645	1,155
Age, yr	55.8 (13.4)	53.6 (12.2)	54.0 (12.7)	53.9 (12.5)	54.3 (12.7)	55.0 (13.2)	55.1 (12.9)	56.0 (13.2)	57.8 (13.2)	58.6 (13.3)	56.8 (13.2)	58.6 (13.2)	58.1 (12.9)	58.3 (12.8)	56.9 (13.1)	57.9 (12.8)	58.3 (12.3)	59.6 (12.5)	58.9 (12.7)
Sex, M	2,393 (41%)	2,331 (49%)	2,770 (50%)	2,265 (47%)	2,615 (47%)	1,465 (45%)	2,369 (45%)	1,948 (43%)	1,830 (41%)	1,174 (41%)	1,055 (51%)	1,792 (44%)	1,641 (46%)	1,283 (46%)	1,444 (49%)	1,178 (46%)	1,599 (47%)	1,779 (49%)	578 (50%)
Males																			
BMI, kg/m^2	25.3 (3.2)	25.3 (3.2)	25.3 (3.1)	25.4 (3.2)	24.5 (4.1)	25.4 (3.4)	25.6 (3.3)	25.7 (3.3)	25.7 (3.3)	25.9 (3.5)	25.6 (3.3)	25.8 (3.5)	25.9 (3.4)	25.9 (3.4)	26.1 (3.6)	25.9 (3.5)	25.9 (3.3)	26.3 (3.7)	26.3 (3.6)
Height, cm	174.0 (6.9)	174.6 (6.8)	174.7 (6.8)	174.9 (7.0)	174.8 (7.0)	175.1 (7.1)	174.5 (7.0)	174.4 (6.9)	174.6 (7.1)	174.1 (6.9)	175.9 (7.2)	175.2 (7.1)	175.5 (6.9)	175.8 (6.8)	176.1 (7.0)	175.6 (6.8)	176.0 (6.8)	175.8 (6.8)	176.0 (6.9)
Weight, kg	76.5 (10.8)	77.0 (10.7)	77.2 (10.8)	77.7 (10.7)	77.7 (10.9)	78.0 (11.2)	78.0 (11.2)	78.0 (11.2)	78.3 (11.1)	78.7 (11.6)	79.1 (11.3)	79.1 (11.9)	79.9 (11.6)	80.1 (11.7)	81.0 (12.1)	79.8 (11.7)	80.2 (11.5)	81.4 (12.8)	81.6 (13.0)
Females																			
BMI, kg/m^2	24.1 (3.9)	24.3 (4.2)	24.4 (4.0)	24.1 (3.9)	24.5 (4.1)	24.2 (4.2)	24.6 (4.2)	24.6 (4.1)	24.6 (4.2)	25.2 (4.5)	25.0 (4.4)	24.5 (4.2)	24.6 (4.2)	24.3 (4.2)	24.7 (4.4)	24.4 (4.3)	24.4 (4.1)	24.7 (4.5)	24.9 (4.6)
Height, cm	162.3 (6.5)	162.5 (6.6)	162.4 (6.4)	162.9 (6.4)	162.6 (6.4)	162.5 (6.6)	162.9 (6.7)	162.9 (6.5)	163.0 (6.5)	161.9 (6.6)	162.8 (6.6)	162.5 (6.8)	163.4 (6.3)	163.9 (6.4)	163.4 (6.7)	163.4 (6.6)	164.0 (6.1)	163.7 (6.2)	163.9 (6.4)
Weight, kg	63.3 (10.5)	64.0 (11.5)	64.2 (10.8)	63.8 (10.5)	64.7 (11.1)	63.7 (10.9)	65.2 (11.2)	65.2 (11.1)	65.3 (11.4)	65.8 (11.6)	66.0 (11.8)	64.8 (11.6)	65.7 (11.6)	65.2 (11.4)	65.9 (12.0)	65.3 (12.0)	65.5 (11.4)	66.1 (12.1)	66.9 (13.3)
Higher education										657 (23%)	675 (33%)	1,148 (28%)	1,023 (29%)	901 (32%)	787 (27%)	768 (30%)	1,083 (32%)	1,047 (29%)	378 (33%)
Smoking status																			
Current	1,467 (25%)	1,083 (21%)	1,247 (23%)	1,000 (21%)	1,177 (21%)	566 (17%)	1,020 (19%)	813 (18%)	783 (18%)	445 (16%)	391 (19%)	744 (18%)	632 (18%)	441 (16%)	552 (19%)	384 (15%)	478 (14%)	615 (17%)	207 (18%)
Ex-smoker	1,082 (18%)	1,067 (20%)	1,225 (22%)	1,060 (22%)	1,163 (21%)	652 (20%)	1,066 (20%)	825 (18%)	937 (21%)	652 (24%)	561 (27%)	1,078 (27%)	942 (27%)	668 (24%)	750 (25%)	731 (29%)	890 (26%)	955 (26%)	272 (24%)
Never	2,782 (47%)	2,719 (52%)	2,684 (49%)	2,519 (52%)	2,935 (53%)	1,904 (58%)	3,005 (57%)	2,725 (60%)	2,568 (58%)	1,579 (57%)	1,052 (51%)	2,118 (53%)	1,832 (52%)	1,642 (59%)	1,604 (54%)	1,387 (55%)	1,958 (58%)	1,962 (54%)	630 (55%)
Passive	544 (9%)	346 (7%)	373 (7%)	251 (5%)	285 (5%)	155 (5%)	200 (4%)	149 (3%)	158 (4%)	87 (3%)	45 (2%)	89 (2%)	124 (4%)	44 (2%)	52 (2%)	37 (1%)	74 (2%)	110 (3%)	44 (4%)
Distance to major roads, m										621 (924)	515 (745)	473 (897)	473 (930)	595 (934)	640 (886)	744 (1,488)	661 (1,316)	525 (905)	533 (1,086)
Urbanization																			
Urban										513 (18%)	626 (31%)	1,253 (31%)	1,001 (28%)	572 (20%)	383 (13%)	506 (20%)	668 (20%)	620 (17%)	301 (26%)
Periurban										1,905 (67%)	1,227 (60%)	2,368 (59%)	1,888 (53%)	1,916 (69%)	1,987 (67%)	1,663 (65%)	2,270 (67%)	2,509 (69%)	722 (63%)
Rural										426 (15%)	199 (10%)	412 (10%)	647 (18%)	307 (11%)	589 (20%)	372 (15%)	467 (14%)	516 (14%)	132 (11%)
Season of assessment																			
Spring	1,867 (32%)	1,368 (26%)	1,224 (22%)	1,559 (32%)	1,672 (30%)	948 (29%)	1,345 (25%)	1,453 (32%)	1,397 (31%)	709 (25%)	1 (0%)	1,474 (37%)	1,081 (31%)	814 (29%)	890 (30%)	875 (34%)	646 (19%)	838 (23%)	744 (64%)
Summer	1,019 (17%)	1,396 (27%)	1,273 (23%)	1,279 (26%)	1,677 (30%)	1,159 (35%)	1,220 (23%)	842 (19%)	1,467 (37%)	662 (23%)	261 (13%)	1,142 (28%)	720 (20%)	657 (24%)	871 (29%)	504 (20%)	858 (25%)	810 (22%)	361 (31%)
Fall	1,372 (23%)	1,321 (25%)	1,585 (29%)	1,016 (21%)	1,644 (30%)	849 (26%)	1,468 (28%)	1,611 (36%)	820 (18%)	1,344 (47%)	1,657 (81%)	1,050 (26%)	1,477 (42%)	1,103 (39%)	1,056 (36%)	1,004 (40%)	1,745 (51%)	1,732 (48%)	0 (0%)
Winter	1,587 (27%)	1,130 (22%)	1,447 (26%)	976 (20%)	567 (10%)	321 (10%)	1,258 (24%)	606 (13%)	614 (14%)	129 (5%)	133 (6%)	367 (9%)	258 (7%)	221 (8%)	142 (5%)	158 (6%)	156 (5%)	265 (7%)	50 (4%)

Definition of abbreviation: BMI = body mass index.
Data are presented as mean (standard deviation) or number of subjects (percent). No information on education, distance to major roads, and urbanization was available for the years 1993–2002, because this information could not be linked to the Swiss National Cohort.

participants who had restrictive spirometry (28). We looked at the subgroups of those who self-reported as having asthma or as having breathing difficulties and respiratory diseases, stratified by GLI-defined AO, to see if the populations reported as sicker over time.

Results

Population Characteristics

The population demographics are shown in Table 1. Age increased slightly over the years, from 55.8 in 1993 to 58.9 in 2012, whereas sex and education remained stable. There was a shift in current smokers from 25% to 18% and an increase in former smokers from 18% to 24% from years 1993 to 2012. Distance to major roads, season of assessment, and urbanization fluctuated throughout the years because of the LuftiBus schedule.

Prevalence of AO from 1993 to 2012

Adjusted prevalence of AO from 1993 to 2012 using the GLI, Hankinson, and GOLD definitions is shown in Table 2. We found an increased prevalence of AO from 1993 and 2012, from 6.1% (95% confidence interval [CI], 5.5 to 6.7) to 15.6% (95% CI, 13.8 to 17.3), based on the GLI definition. Similar estimates were found using the Hankinson definition of AO, increasing from 5.3% (95% CI, 4.7 to 5.9) in 1993 to 15.4% (95% CI, 13.6 to 17.1) in 2012. The GOLD estimate was consistently higher than GLI and Hankinson for all years. Restrictive pattern spirometry prevalence was 17.9% (95% CI, 17.0 to 18.9) in 1993 and decreased to 10.0% (95% CI, 8.5 to 11.4) by 2012. FEV_1 remained stable, whereas FVC increased from an average 3.7 liters in 1993 to 4.0 liters in 2012.

We applied loess smoothing to the LuftiBus-only data from 1993 to 2012 and separated by sex and smoking status. Prevalence was derived from the adjusted Poisson models and plotted annually using GLI-defined AO (Figure 2) and Hankinson-defined AO (Figure 3). In Figure 2, we saw that the prevalence of AO by 2012 was higher in males than in females. Prevalence of male current smokers in 1993 was 13.7% and increased to 35.3% by 2012. Male former smokers had a higher prevalence of AO in 2012 than female current smokers, at 25.9% compared with 19.2%.

Table 2. Airway obstruction prevalence and lung function, by year

Airway Obstruction Definition	1993	1994	1995	1996	1997	1998	1999	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GLI	6.1%	6.0%	4.5%	5.0%	4.1%	5.2%	4.6%	5.0%	8.2%	9.7%	9.5%	9.4%	10.9%	11.2%	13.1%	12.8%	14.0%	15.6%
95% CI	5.5–6.7	5.3–6.6	3.9–5.0	4.4–5.6	3.6–4.6	4.4–5.9	4.0–5.2	4.4–5.7	7.6–8.9	8.5–10.8	8.7–10.3	8.6–10.3	9.9–11.9	10.2–12.2	12.0–14.2	11.8–13.8	13.1–15.0	13.8–17.3
Hankinson	5.3%	5.3%	3.9%	4.6%	3.6%	4.6%	4.6%	4.7%	8.2%	9.8%	9.0%	9.4%	10.2%	10.5%	12.7%	11.9%	13.2%	15.4%
95% CI	4.7–5.9	4.7–5.9	3.4–4.4	4.0–5.2	3.1–4.1	3.9–5.3	4.0–5.1	4.1–5.3	7.6–8.9	8.6–10.9	8.2–9.8	8.5–10.2	9.2–11.2	9.5–11.5	11.6–13.8	11.0–12.9	12.2–14.1	13.6–17.1
GOLD	9.6%	9.3%	5.7%	8.1%	6.8%	8.0%	8.1%	7.8%	15.5%	16.6%	16.1%	17.3%	18.7%	19.0%	21.7%	21.2%	24.1%	27.2%
95% CI	8.8 –10.4	8.5–10.1	5.1–6.3	7.3–8.9	6.1–7.5	7.1–8.9	7.3–8.8	7.0–8.5	14.7–16.4	15.1–18.0	15.1–17.1	16.2–18.4	17.5–20.0	17.8–20.2	20.4–23.1	20.0–22.4	22.9–25.3	25.0–29.3
Restrictive pattern	17.9%	14.8%	15.4%	14.9%	16.0%	12.7%	17.8%	18.0%	11.1%	10.8%	12.3%	11.7%	9.6%	8.9%	8.7%	9.6%	10.4%	10.0%
95% CI	17.0–18.9	13.8–15.7	14.5–16.4	13.9–15.9	15.1–17.0	11.6–13.9	16.7–18.8	16.9–19.1	10.4–11.9	9.6–12.0	11.4–13.2	10.7–12.6	8.6–10.6	8.0–9.8	7.8–9.6	8.7–10.5	9.6–11.3	8.5–11.4
FEV_1/FVC (%)	79.5 (7.7)	79.7 (7.6)	80.3 (7.2)	80.1 (7.3)	80.8 (7.1)	80.2 (7.5)	80.3 (7.5)	80.9 (7.7)	77.1 (8.2)	76.0 (7.5)	76.0 (7.5)	76.4 (8.7)	76.0 (8.0)	75.6 (7.9)	75.0 (7.9)	74.7 (7.8)	74.2 (8.2)	73.7 (8.3)
FEV_1, L	2.9 (0.9)	3.1 (0.9)	3.1 (0.9)	3.1 (0.9)	3.1 (0.9)	3.1 (0.9)	3.0 (0.8)	3.0 (0.8)	2.9 0.9)	3.1 (0.9)	2.9 (0.9)	3.0 (0.9)	3.1 (0.9)	3.1 (0.9)	3.1 (0.9)	3.0 (0.9)	2.9 (0.9)	2.9 (0.9)
FVC, L	3.7 (1.1)	3.9 (1.1)	3.9 (1.1)	3.9 (1.1)	3.9 (1.1)	3.9 (1.1)	3.7 (1.0)	3.7 (1.0)	3.8 (1.1)	4.0 (1.1)	3.8 (1.1)	4.0 (1.1)	4.1 (1.2)	4.1 (1.1)	4.1 (1.1)	4.1 (1.1)	4.0 (1.1)	4.0 (1.1)

Definition of abbreviations: CI = confidence interval; GLI = Global Lung Initiative; GOLD = Global Initiative for Chronic Obstructive Lung Disease; FEV_1 = forced expiratory volume in 1 second; FVC = forced vital capacity.
Prevalence is presented as a percentage with the 95% CI, whereas lung function results are presented as mean (standard deviation). Note that at 2005 and 2011, the spirometry device changed.

In Figure 3, we saw Hankinson-defined AO increased for both sexes. Prevalence of female current smokers in 1993 was 10.1% and increased to 29.1% by 2012. Although Hankinson reported higher rates of AO for women in all smoking categories, for males, the Hankinson rates tended to be lower than the GLI equivalents, particularly for current and former smokers.

Checking the Robustness of the Temporal Trend of AO

On the basis of adjusted analysis including education, VGDF, and COPD Roadshow, we saw that the prevalence rates of having GLI- or Hankinson-defined AO was 1.54 (95% CI, 1.22 to 1.93) and 1.65 (95% CI, 1.33 to 2.04) in the year 2012 compared with the year 2003, respectively (Table 3). Therefore, the upward trend of AO in the population remained strong even after adjusting for additional confounders. The full output for the logistic regression model is provided in Table E1 in the online supplement.

We repeated the loess smoothed plots for adjusted GLI- and Hankinson-defined AO and stratified by age group. For GLI-defined AO, the prevalence rates were high for those aged 65 years and older; however, the prevalence for younger age groups showed a steady increase over time (Figure E2). The same was seen for Hankinson-defined AO, which showed steady increases for all age groups (Figure E3).

We restricted our sensitivity analysis to participants in the Canton of Zurich ($n = 18{,}597$). We ran adjusted Poisson regression models and saw that the rate of having GLI- or Hankinson-defined AO was 1.66 (95% CI, 1.19 to 2.29) and 1.74 (95% CI, 1.29 to 2.33) times higher in the year 2012 than in the year 2003, respectively (Table E4). Therefore, even after accounting for the LuftiBus traveling outside of Zurich more often in the later years, the trend in AO from 2003 to 2012 still existed when limited to one region.

We looked at participants who self-reported as having asthma ($n = 1{,}175$) from the 2004–2012 LuftiBus-SNC data to see if they influenced prevalence. We plotted GLI and Hankinson prevalence using the adjusted Poisson models. Participants with asthma had high rates of AO, but there was no obvious time trend (Figures E5 and E6).

Last, we assessed self-reported breathing difficulties and disease status over time. We saw little change in those who complained of breathing difficulties; however, there were fluctuations across disease status that included a decrease in cough and bronchitis and cardiovascular disease in those who did have AO (Table E7). Ultimately, there were minimal changes over the years in these items.

Discussion

In our series of 18 prevalence studies, we found an increase in AO prevalence from 1993 to 2012. The rate of AO was 1.5 and 1.6 times higher in 2012 compared with 2003 when using the GLI and Hankinson definitions, respectively, after extensive adjustments to control for differences in populations across the years.

Because the increases were substantial, we dug deeper into the methodological contributions by focusing on subpopulations such as Zurich and self-reported asthma, disease status, and breathing difficulties. The increase still existed when we limited the analysis to Zurich. Zurich is a good representation of Switzerland and shows little deviation from the general population, which leads us to say there is an increase in AO in the general population of Switzerland.

The overall prevalence of AO in our cohort in 2010 is 12.8% using GLI-defined AO, which is close to the worldwide estimated prevalence of COPD of 11.7% (2). One of the strengths of the LuftiBus campaign is the ability to adjust for many confounders shown to influence AO. The results of previous temporal trend studies are inconsistent, limited to physician-diagnosed COPD and adjustment for confounding; are often limited to age, sex, or smoking; and do not account for both air pollution and occupational VGDF. We observed an increase in prevalence, regardless of smoking status or age group.

Although ambient air pollution levels in Switzerland remained low during the years of this cohort, a 2012 publication in the *Swiss Forestry Journal* reported that air pollution peaked from the 1960s to the 1990s (20, 29). The World Health Organization reported on Swiss tobacco trends (30), showing that per capita cigarette consumption peaked in the 1970s and 1980s. Until 2010, there was little protection of the population against passive smoking in public spaces. We speculate that this increase in air pollution, tobacco consumption, and passive smoking could

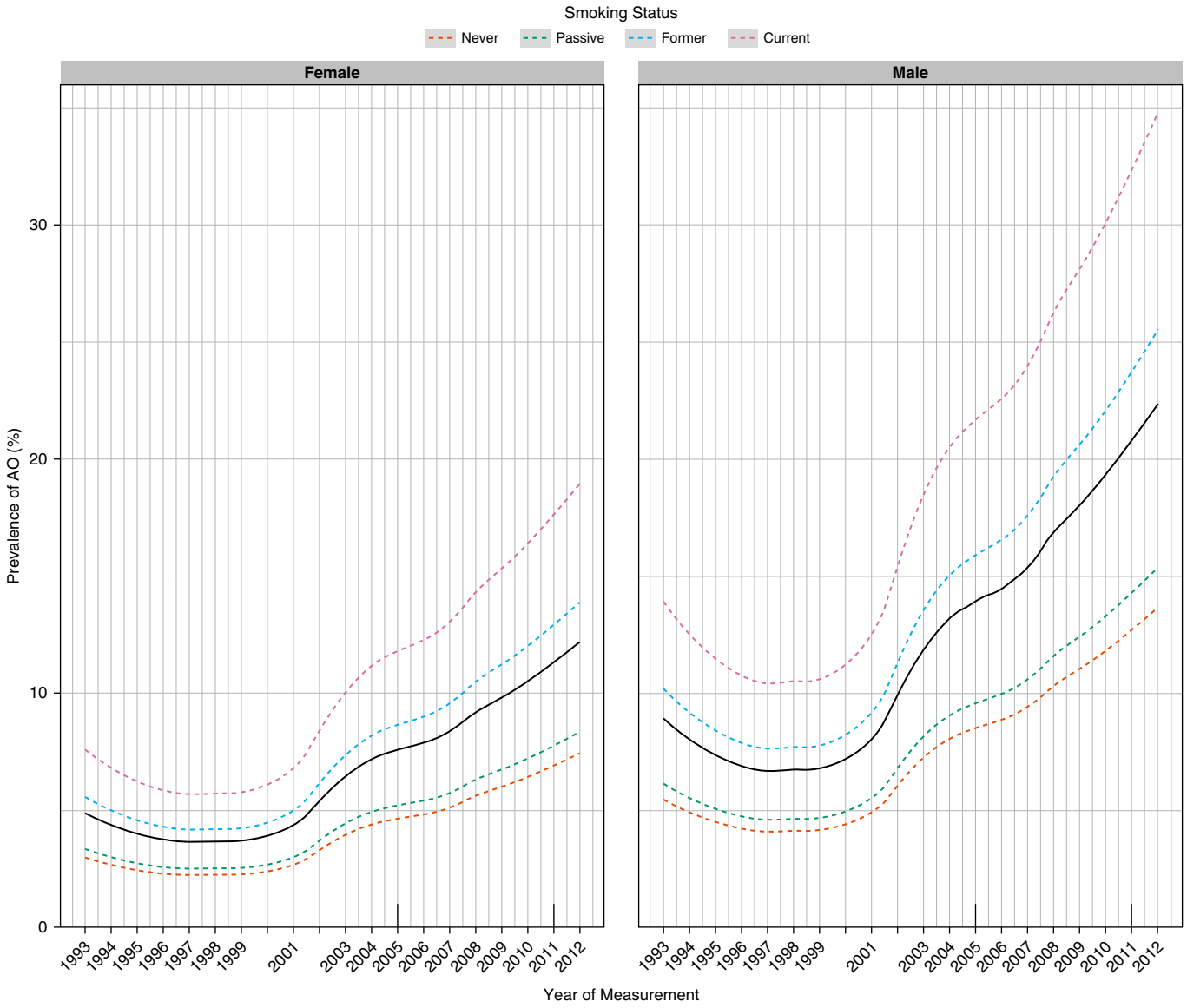

Figure 2. Prevalence of airway obstruction (AO) as defined by the Global Lung Initiative annually from 1993 to 2012, stratified by sex and smoking status. Dashed lines represent prevalence by smoking status; solid lines represent overall prevalence by sex; and solid lines at 2005 and 2011 along the *x*-axis represent the time period when the spirometry device changed.

contribute to the increase trend in AO in our study, given that the development of AO takes decades.

In 2010, the Swiss federal government passed a passive smoking law dictating minimum requirements regarding smoking in public spaces. Individual cantons could impose stricter legislation. Since the introduction of this law, smoking in enclosed spaces open to the public or serving as a workplace is prohibited (31). Because of this improvement in air quality, it is possible in the upcoming decades that we will see a decrease in AO, assuming smoking and environmental air pollutants play a role in the prevalence trend. The increase in AO may be a result of these environmental factors before these restrictions.

Several studies have attempted to explain the prevalence trends of AO in Italy, Norway, and Spain (3, 4, 6), although none of them is conclusive. Both the Italian and Norwegian research groups found an increase in AO prevalence, whereas the Spanish research group reported a decrease. The Italian research group suggested that tobacco use, air pollutants, urban living environment, and occupational exposures seemed to be the primary sources of increase in COPD. Our data showed that occupational exposures to VGDF resulted in 3.1 and 3.2 times higher chance of AO when using the GLI and Hankinson criteria of diagnosis, respectively, after adjusting for all other demographic variables. The Norwegian study reported a similarly strong increase in COPD prevalence from 1997 to 2005; however, it could be due to the methodological design of their study. Their dataset for 2007 comprised the second follow-up data of a 20-year cohort study, and as such a potential loss to follow-up

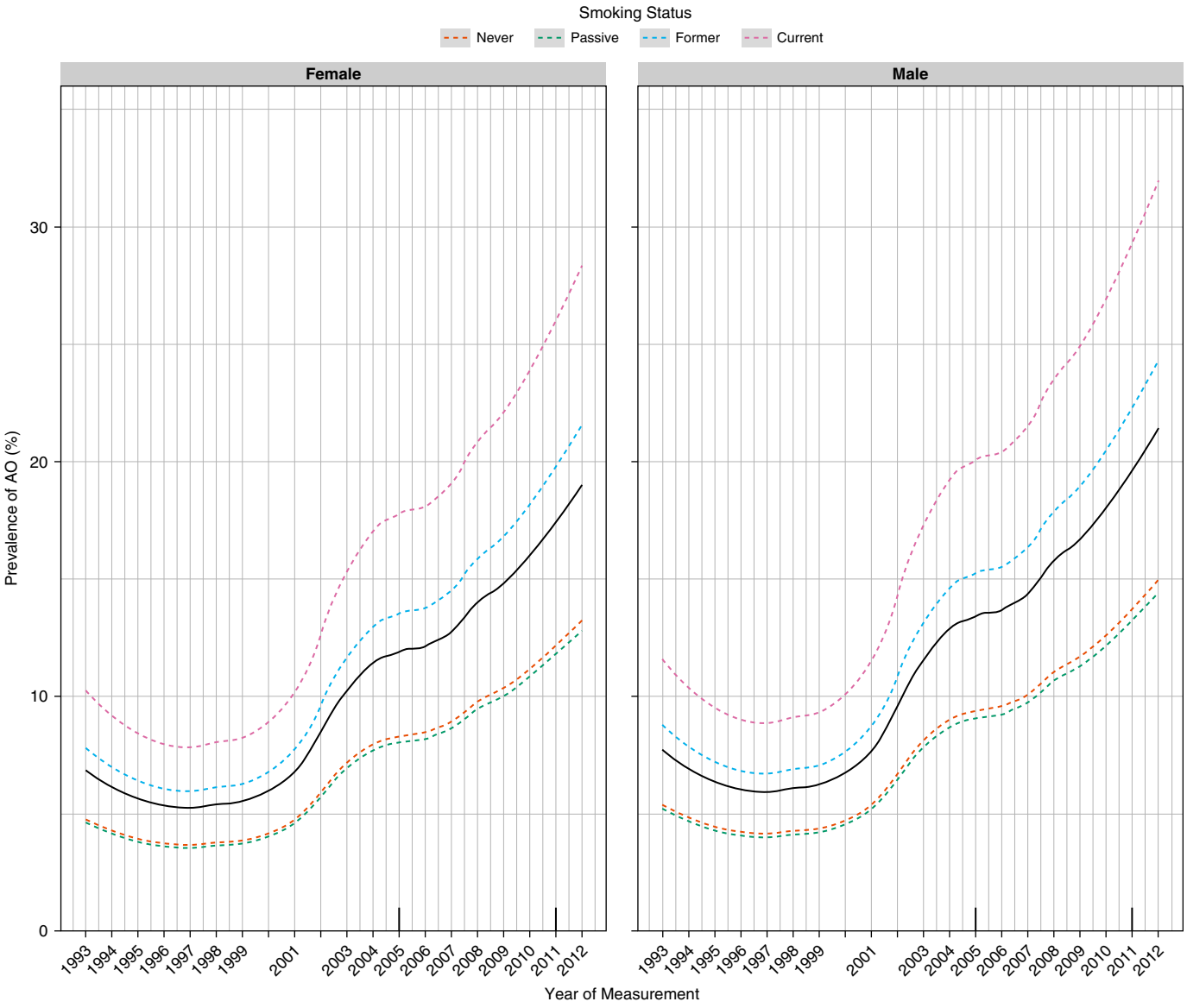

Figure 3. Prevalence of airway obstruction (AO) defined by Hankinson annually from 1993 to 2012, stratified by sex and smoking status. Dashed lines represent prevalence by smoking status; solid lines represent overall prevalence by sex; and solid lines at 2005 and 2011 along the *x*-axis represent the time period when the spirometry device changed.

could bias the temporal trend. For both the Italian and Norwegian studies, using follow-up data could have overestimated the increase in prevalence because of an aging study population. The Spanish research group reported a decrease in prevalence of COPD between the years 1997 and 2007, different from many other studies on temporal COPD trends. Their findings could have potentially been affected by a sicker population in 1997 than in 2007.

Our study has advantages, such as a large sample size and the ability to match the LuftiBus data with the Swiss census, to model important risk factors. The spirometry testing was performed with trained staff who were required to undergo training at least two times per year conducted by an expert pulmonologist according to strict guidelines. The technicians tested the devices daily to ensure precise calibration. However, the LuftiBus was not based on a sampling procedure, and those who participated did so voluntarily. Given that public awareness of COPD, asthma, and other pulmonary diseases has increased over the years, those with respiratory symptoms or chronic exposure to VGDF may be more inclined to participate. Participants may be less healthy than the general population, resulting in a volunteer bias, which could overestimate both the absolute and adjusted prevalence trends (32). The self-reported breathing difficulties and disease status over time showed no obvious time trend of a sicker population. A 2015 World Health Organization report on tobacco consumption showed that Switzerland had a 20% prevalence of consumption in 2014, similar to the 18% prevalence of smoking we saw in our dataset (33). Our study population was similarly comparable to the general population regarding sex and age. These similarities help to strengthen our

Table 3. Global Lung Initiative–, Hankinson-, and Global Initiative for Chronic Obstructive Lung Disease standard–defined airway obstruction prevalence ratios compared with year 2003

Airway Obstruction Definition	2004	2005	2006	2007	2008	2009	2010	2011	2012
GLI	0.65	0.81	0.90	1.22	0.98	1.19	0.98	1.36	1.54
95% CI	0.54–0.78	0.70–0.95	0.76–1.05	1.04–1.42	0.84–1.15	1.01–1.39	0.83–1.16	1.15–1.61	1.22–1.93
Hankinson	0.63	0.78	0.88	1.15	0.95	1.20	0.94	1.29	1.65
95% CI	0.53–0.76	0.68–0.90	0.76–1.03	0.99–1.34	0.82–1.11	1.03–1.39	0.80–1.10	1.10–1.52	1.33–2.04
GOLD	0.83	0.83	1.00	1.18	1.07	1.22	0.99	1.37	1.50
95% CI	0.74–0.93	0.76–0.91	0.91–1.09	1.08–1.30	0.98–1.18	1.11–1.33	0.89–1.09	1.24–1.50	1.33–1.70

Definition of abbreviations: CI = confidence interval; COPD = chronic obstructive pulmonary disease; GLI = Global Lung Initiative; GOLD = Global Initiative for Chronic Obstructive Lung Disease.
The table shows prevalence ratios of having GLI-, Hankinson-, or GOLD-defined airway obstruction compared with year 2003. The Poisson regressions were adjusted for age, sex, body mass index, smoking status, residential distance to major roads, education level, occupational exposure, urbanization, participation in COPD Roadshow, altitude, and season of LuftiBus assessment. Note that at 2005 and 2011, the spirometry device changed.

argument that this sample is a population sample and representative of the general population in Switzerland, not necessarily indicating a sicker population over the years.

The 1993–2002 data did not contain sufficient information so that subjects could be identified; thus, we were unable to confirm if this dataset contained participants included in the LuftiBus-SNC dataset from 2003 to 2012, for which we have patient-identifiable information. This could lead to participants' being represented more than once in the prevalence analysis. We have repeat measurements ($n = 3{,}269$) from the LuftiBus-SNC dataset from 2003 to 2012 that were unused in the analysis for this study. We looked at the crude prevalence of GLI- and Hankinson-defined AO and it increases with each visit number. Regardless of these considerations, any repeated participants in the analysis from 1993 to 2012 would change neither the direction nor the magnitude of the temporal prevalence trend, because those participants are equally likely to repeat in any year. Therefore, we would still see an increase in AO.

Prebronchodilator measurements may potentially overestimate the prevalence rates compared with post-bronchodilator measurements. A Norwegian study (4) had both pre- and post-bronchodilator data and found a 7% higher prevalence in the prebronchodilator data than in the post-bronchodilator data. This implies that we could be overestimating the prevalence of AO; however, this would not affect the temporal trend we see.

Another limitation of the LuftiBus data is that two-thirds of our study population reside in Zurich. Therefore, although our sample size is large, this could limit generalizability. However, Zurich rarely substantially deviates from the Swiss average, and the age structure of the adult population in the Canton of Zurich is very similar to that of Switzerland as a whole.

Last, the multiple spirometer devices used may bias the trend estimates because of measurement error (34). The LuftiBus used devices manufactured consistently from the same company over the years (CareFusion is the parent organization of SensorMedics). Previous papers (35–37) have shown that there is little difference between devices when tested regularly, and devices used in a pulmonary laboratory setting are more accurate than those used in clinical practice. A Norwegian paper that used both SensorMedics Vmax devices found that the Legacy was 2.5% lower, on average, for FEV_1 values than the Encore, which, if adjusted for in our study, would highlight a larger increase in prevalence over time (38). Isolating the Vmax Encore, in use from 2005 to 2010, the trend increases from 9.4% to 12.2% for GLI-defined AO, showing that even with one device, we are still seeing an increase. Because of these factors, it is reasonable to believe that the trend over time from 1993 to 2012 is an accurate indicator of an increase of AO and not necessarily indicative of a sicker population over the years.

There are substantial public health implications of a true rise of AO prevalence. The BOLD (Burden of Obstructive Lung Disease) study (39) found that participants with COPD were more likely to have heart disease, hypertension, and diabetes. A follow-up paper (40) suggested that severe COPD could have a larger negative impact on health status than cardiovascular disease and diabetes. A rise in AO could increase hospital use, medication use, and direct/indirect medical costs if AO trends worsen over time. An increase in AO in Switzerland could also indicate an increase in other countries with similar demographics, air pollution trends, occupational exposures, and rates of smoking. We speculate that this increase in AO in Switzerland could be indicative of what can be expected in other countries if strong public health actions are not taken against these risk factors.

AO seems to be increasing worldwide, but only few studies have been done to assess prevalence trends. Temporal prevalence studies are essential in assessing whether there is a true increase within populations. Although it is well known that smoking has a strong impact on the incidence of AO, more needs to be done to assess the environmental and occupational impact on temporal AO trends.

Conclusions

We found that the prevalence of GLI-defined AO increased from 6.1% to 15.6% over a 20-year period. After adjusting for several well-known risk factors for AO, we still observed a statistically significant increase in the prevalence over time when looking at a decade of data. We feel confident in saying that this is a true upward trend of AO in the general Swiss population. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

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References

1 Vos T, Allen C, Arora M, Barber RM, Bhutta ZA, Brown A, *et al*.; GBD 2015 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet* 2016; 388:1545–1602.

2 Adeloye D, Chua S, Lee C, Basquill C, Papana A, Theodoratou E, *et al*.; Global Health Epidemiology Reference Group (GHERG). Global and regional estimates of COPD prevalence: systematic review and meta-analysis. *J Glob Health* 2015;5:020415.

3 Maio S, Baldacci S, Carrozzi L, Pistelli F, Angino A, Simoni M, *et al*. Respiratory symptoms/diseases prevalence is still increasing: a 25-yr population study. *Respir Med* 2016;110:58–65.

4 Waatevik M, Skorge TD, Omenaas E, Bakke PS, Gulsvik A, Johannessen A. Increased prevalence of chronic obstructive pulmonary disease in a general population. *Respir Med* 2013;107:1037–1045.

5 Kotaki K, Ikeda H, Fukuda T, Yuhei K, Yuki F, Kawasaki M, *et al*. Trends in the prevalence of COPD in elderly individuals in an air-polluted city in Japan: a cross-sectional study. *Int J Chron Obstruct Pulmon Dis* 2019;14:791–798.

6 Soriano JB, Ancochea J, Miravitlles M, García-Río F, Duran-Tauleria E, Muñoz L, *et al*. Recent trends in COPD prevalence in Spain: a repeated cross-sectional survey 1997–2007. *Eur Respir J* 2010;36: 758–765.

7 Hwang YI, Park YB, Yoo KH. Recent trends in the prevalence of chronic obstructive pulmonary disease in Korea. *Tuberc Respir Dis (Seoul)* 2017;80:226–229.

8 Gershon AS, Wang C, Wilton AS, Raut R, To T. Trends in chronic obstructive pulmonary disease prevalence, incidence, and mortality in Ontario, Canada, 1996 to 2007: a population-based study. *Arch Intern Med* 2010;170:560–565.

9 Doucet M, Rochette L, Hamel D. Incidence, prevalence, and mortality trends in chronic obstructive pulmonary disease over 2001 to 2011: a public health point of view of the burden. *Can Respir J* 2016;2016: 7518287.

10 Ford ES, Mannino DM, Wheaton AG, Giles WH, Presley-Cantrell L, Croft JB. Trends in the prevalence of obstructive and restrictive lung function among adults in the United States: findings from the National Health and Nutrition Examination surveys from 1988–1994 to 2007–2010. *Chest* 2013;143:1395–1406.

11 Vasankari TM, Impivaara O, Heliövaara M, Heistaro S, Liippo K, Puukka P, *et al*. No increase in the prevalence of COPD in two decades. *Eur Respir J* 2010;36:766–773.

12 Backman H, Eriksson B, Rönmark E, Hedman L, Stridsman C, Jansson SA, *et al*. Decreased prevalence of moderate to severe COPD over 15 years in northern Sweden. *Respir Med* 2016;114:103–110.

13 Bhatta L, Leivseth L, Mai XM, Chen Y, Henriksen AH, Langhammer A, *et al*. Prevalence and trend of COPD from 1995–1997 to 2006–2008: the HUNT Study, Norway. *Respir Med* 2018;138:50–56.

14 Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, *et al*.; ERS Global Lung Function Initiative. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the Global Lung Function 2012 equations. *Eur Respir J* 2012;40:1324–1343.

15 Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. *Am J Respir Crit Care Med* 1999;159:179–187.

16 Gerald LB, Bailey WC. Global Initiative for Chronic Obstructive Lung Disease. *J Cardiopulm Rehabil* 2002;22:234–244.

17 R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2019 [accessed 2018 Jan 17]. Available from: http://www.R-project.org/.

18 Cleveland WS, Devlin SJ. Locally weighted regression: an approach to regression analysis by local fitting. *J Am Stat Assoc* 1988;83:596–610.

19 Li J, Sun S, Tang R, Qiu H, Huang Q, Mason TG, *et al*. Major air pollutants and risk of COPD exacerbations: a systematic review and meta-analysis. *Int J Chron Obstruct Pulmon Dis* 2016;11:3079–3091.

20 Heldstab J, Leippert F, Wüthrich P, Künzle T; Federal Office for the Environment (FOEN). PM10 and PM2.5 ambient concentrations in Switzerland: modelling results for 2005, 2010, 2020. Bern, Switzerland: FOEN; 2013.

21 Schikowski T, Mills IC, Anderson HR, Cohen A, Hansell A, Kauffmann F, *et al*. Ambient air pollution: a cause of COPD? *Eur Respir J* 2014;43: 250–263.

22 Prescott E, Lange P, Vestbo J. Socioeconomic status, lung function and admission to hospital for COPD: results from the Copenhagen City Heart Study. *Eur Respir J* 1999;13:1109–1114.

23 Fuller-Thomson E, Chisholm RS, Brennenstuhl S. COPD in a population-based sample of never-smokers: interactions among sex, gender, and race. *Int J Chronic Dis* 2016;2016:5862026.

24 Seemungal TAR, Mohammed S, Mohammed H, Sakhamuri S, Pinto-Perreira L, Teelucksingh S, *et al*. A lower level of education is related to disease severity and biomass exposure in west Indian subjects with COPD [abstract]. *Am J Respir Crit Care Med* 2014;189:A2204.

25 Blanc PD. Occupation and COPD: a brief review. *J Asthma* 2012;49:2–4.

26 Wang C, Puhan MA, Furrer R. Generalized spatial fusion model framework for joint analysis of point and areal data. *Spat Stat* 2018;23: 72–90.

27 Rochat MK, Laubender RP, Kuster D, Braendli O, Moeller A, Mansmann U, *et al*. Spirometry reference equations for central European populations from school age to old age. *PLoS One* 2013;8:e52619.

28 Backman H, Eriksson B, Hedman L, Stridsman C, Jansson SA, Sovijärvi A, *et al*. Restrictive spirometric pattern in the general adult population: methods of defining the condition and consequences on prevalence. *Respir Med* 2016;120:116–123.

29 Augustin S, Achermann B. Deposition of air pollutants in Switzerland: development, current situation and assessment [in German]. *Schweiz Z Forstwes* 2012;163:323–330.

30 World Health Organization (WHO). Switzerland: regional report on trends in tobacco smoking 1955–2025. Geneva, Switzerland: WHO; 2018.

31 Schweizerische Eidgenossenschaft. Bundesgesetz zum Schutz vor Passivrauchen. von 2008, SR818.31, 4–6 (2008).

32 Bopp M, Braun J, Faeh D; Swiss National Cohort Study Group. Variation in mortality patterns among the general population, study participants, and different types of nonparticipants: evidence from 25 years of follow-up. *Am J Epidemiol* 2014;180:1028–1035.

33 World Health Organization (WHO). WHO report on the global tobacco epidemic, 2015: raising taxes on tobacco. Geneva, Switzerland: WHO; 2015. p. 125.

34 Künzli N, Kuna-Dibbert B, Keidel D, Keller R, Brändli O, Schindler C, *et al*.; SAPALDIA team. Longitudinal validity of spirometers—a challenge in longitudinal studies. *Swiss Med Wkly* 2005;135:503–508.

35 Schermer TRJ, Verweij EHA, Cretier R, Pellegrino A, Crockett AJ, Poels PJP. Accuracy and precision of desktop spirometers in general practices. *Respiration* 2012;83:344–352.

36 Hegewald MJ, Gallo HM, Wilson EL. Accuracy and quality of spirometry in primary care offices. *Ann Am Thorac Soc* 2016;13:2119–2124.

37 Künzli N, Ackermann-Liebrich U, Keller R, Perruchoud AP, Schindler C; SAPALDIA team. Variability of FVC and FEV_1 due to technician, team, device and subject in an eight centre study: three quality control studies in SAPALDIA. *Eur Respir J* 1995;8:371–376.

38 Vold ML, Aasebø U, Melbye H. Low FEV_1, smoking history, and obesity are factors associated with oxygen saturation decrease in an adult population cohort. *Int J Chron Obstruct Pulmon Dis* 2014;9: 1225–1233.

39 Buist AS, McBurnie MA, Vollmer WM, Gillespie S, Burney P, Mannino DM, *et al*.; BOLD Collaborative Research Group. International variation in the prevalence of COPD (the BOLD Study): a population-based prevalence study. *Lancet* 2007;370:741–750.

40 Janson C, Marks G, Buist S, Gnatiuc L, Gislason T, McBurnie MA, *et al*. The impact of COPD on health status: findings from the BOLD Study. *Eur Respir J* 2013;42:1472–1483.